13th Thermal & Fluids Analysis Workshop

Paper Session Abstracts

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INTERDISCIPLINARY PAPER SESSION

Chair: Georg Siebes, Jet Propulsion Laboratory

Integration of Thermal Analysis in the ESA Concurrent Design Facility

Hans Peter de Koning, ESA/ESTEC
Andrea Santovincenzo, ESA/ESTEC

ABSTRACT:
The Concurrent Design Facility (CDF) was established at ESTEC in 1999, with the objective of creating a multi-disciplinary mission design environment dedicated to the assessment of future space missions. Several scientific missions at pre-Phase A level have been assessed as well as missions from the so-called application programmes (e.g. telecom, earth observation).

In addition, the CDF infrastructure has been used to perform industrial work reviews, to prepare specifications, to co-ordinate international project work and for educational purposes.

The experience has shown that this intensive collaborative environment has significantly improved the efficiency and effectiveness of the mission design activities, while at the same time maintaining—or even improving—the level of quality and accuracy in the delivered work.

The presentation will provide an overview of how the ESA CDF is implemented and operated. Special attention will be given to the way the thermal analysis discipline is integrated in the collaborative environment. Ideas on future enhancements and scale-up of the CDF for Phase B preliminary design and analyses and Phase C/D detailed design, analysis and verification will be discussed.

SMVT CDC Thermal Module: A Paradigm Shift

Saul Miller, The Aerospace Corporation

ABSTRACT:
Five years ago, the Concept Design Center (CDC) at The Aerospace Corporation was formed to provide a focus for Concurrent Engineering at the early stage of the design process. Several teams have been spawned from the initial team, the Space Segment Team, to focus on specialize applications. One of these teams is focused on the conceptual design of the Space Maneuver Vehicle (SMV). Within the Thermal Module of the SST CDC, a linear predictive model was to estimate Thermal Control System (TCS) mass and power. This model had limitations of estimating the TCS mass and power because the SMV utilized new technologies. A new Thermal Module was developed for the Space Maneuver Vehicle Team (SMVT) CDC.

This module is a radical change from previous CDC Thermal Modules used for satellites. The new thermal module sizes the radiator area and the heat transport capacity to meet the desired thermal performance using the algorithms used for spacecraft thermal analysis. The modeling approach for the new thermal module mirrors the approach used for more detailed thermal design synthesis and analysis. The SMVT CDC poses unique challenges to the TCS design synthesis because design iteration must be performed within a 20-minute period. Typically, design synthesis iterations take hours to perform.

The advantage of the new thermal module is the increased fidelity of the modeling process and greater confidence in the estimated TCS mass and power. Since the predicted TCS performance is based upon a methodology used for spacecraft thermal analysis, the output of the Thermal Module should be reproducible by the contractor when the same assumptions are made.

This presentation describes the background for the development of the new Thermal Module, the generic thermal design and analysis process, and the methods used to implement the process within the constraints of the SMVT CDC session.

Advanced Spacecraft Conceptual Design Process at JPL

Robert Miyake, Jet Propulsion Laboratory

ABSTRACT:
JPL has developed an Advanced Projects Design Team ("Team X") to improve the speed and quality of JPL's new mission concepts. The development of this team and process was started in April of 1995. This effort created a reusable study process which utilizes a dedicated team, which has dedicated facilities, equipment, procedures, and tools. Further, it developed a database of initial mission requirements that are easily updated and electronically transferred for use in subsequent project phases. To date over 400 studies have been completed. This team uses concurrent design process, which enables real-time design and resolution of trade issues by all team members as well as visibility across subsystem interfaces. This process also enables early agreement and ownership of decisions by all disciplines. The product of this process has improved the quality of JPL proposals and pre-project efforts. Further it improves phase-A design process and saves both money and schedule.

The Thermal Subsystem Chair develops the thermal design concepts (flight element list, and the mass and electrical power requirements), and subsystem cost. All subsystems are interfaced during the concurrent design process utilizing a PC based server system. Examples of subsystem interfaces are, mission design and programmatics for mission and development time line, the structure subsystem for configuration and fields-of-view requirements, instrument and science for science requirements and instrument interfaces, the electrical power subsystem to support its design (e.g. Solar Array temperature predictions for performance calculations), and propulsion subsystem to support its temperature requirements.

A simple mass and mission definition based algorithm is used to develop flight hardware mass and electrical power requirements. To support this effort, a heritage based hardware and workforce database is maintained.

The output from this chair is a subsystem description, a hardware list, mass and power requirement, and a subsystem cost estimate. Also included in the output is technology development requirement and risk assessment.

Utilization of Integrated High-End Analysis and Design Tools in Real-Time Concurrent Design Environments
Knut Oxnevad, Jet Propulsion Laboratory

ABSTRACT:
The Next Generation Project Development Teams (NPDTs) at the Jet Propulsion Laboratory provides customers with state-of-the-art Concurrent Analysis, Simulation, and Design environments for the early design stages that emphasizes a total Systems approach, and features Multi-Disciplinary design teams, and interconnected, high-end Analysis and Design tools. These tools share and utilize a common 3D geometry of payload and spacecraft for their analyses and design. As a result, teams utilizing the NPDT approach have shown improved analysis accuracy and higher design maturity in the early design phases, and have managed to shrink development time by factors of four and higher. The ability to bring a design from concept to engineering drawing level quality in very short time has also been demonstrated. In the case of a sub-sea probe, engineering level quality was achieved in 3 weeks. Currently, work is being done to introduce supercomputers and massive parallel computing systems to further improve the accuracy of the NPDT analysis, simulation, and design processes. The NPDTs have provided support for payloads, probes, rovers, and dedicated SC studies and proposals, covering orbital and in-situ types of payloads for volcanic vents off the ocean floor, bore-holes in Antarctica, planetary surface and sub surfaces, Earth and planetary orbits, and atmospheric insertions. The concurrent analysis and design method developed and implemented in the NPDT environment can with slight modifications be applied for developing full spacecraft, automobiles, oil & gas platforms, and other types of large and complex systems.

Integrated Analysis of Thermal/Structural/Optical Systems

B. Cullimore, T. Panczak, J. Baumann, Cullimore & Ring Technologies, Inc.
Dr. Victor Genberg, Sigmadyne Inc.
Mark Kahan, Optical Research Associates, Inc.

ABSTRACT:
Productivity bottlenecks for integrated thermal, structural, and optical design activities were identified and systematically eliminated, making possible automated exchange of design information between different engineering specialties. The problems with prior approaches are summarized, then the implementation of the corresponding solutions is documented. Although the goal of this project was the automated evaluation of coupled thermal/optical/structural designs, significant process improvements were achieved for subset activities such as stand-alone thermal, thermal/ structural, and structural/optical design analysis.

Automated Multidisciplinary Optimization of a Space-based Telescope

B. Cullimore, T. Panczak, J. Baumann, Cullimore & Ring Technologies, Inc.
Dr. Victor Genberg, Sigmadyne Inc.
Mark Kahan, Optical Research Associates, Inc

ABSTRACT:
Automated design space exploration was implemented and demonstrated in the form of the multidisciplinary optimization of the design of a space-based telescope. Off-the-shelf software representing the industry standards for thermal, structural, and optical analysis were employed. The integrated thermal/structural/optical models were collected and tasked with finding an optimum design using yet another off-the-shelf program. Using this integrated tool, the minimum mass thermal/structural design was found that directly satisfied optical performance requirements without relying on derived requirements such as isothermality and mechanical stability. Overdesign was therefore avoided, and engineering productivity was greatly improved. This ambitious project was intended to be a pathfinder for integrated design activities. Therefore, difficulties and lessons learned are presented, along with recommendations for future investigations.

Further Data Exchange Standardization for Space Thermal Analysis

Hans Peter de Koning, ESA/ESTEC

ABSTRACT:
Over the last years the STEP-based standards STEP-TAS and STEP-NRF have been developed under ESA funding. STEP-TAS has been implemented in many different thermal-radiative analysis packages, both in Europe and the US. In the European tools ESARAD and THERMICA the import/export interfaces are now reasonable mature and are used in practice.

The presentation will discuss the way forward on the ongoing implementation of the STEP-TAS standard for the exchange of further features beyond the basic thermal-radiative face geometry and thermo-optical properties. These features include kinematic articulation and definition of analysis cases: orbit, attitude, pointing, thermal space environment, etc.

In addition the new stand-alone, bi-directional TRASYS/STEP-TAS converter will be shown, which will be made available from ESA for free of charge download and usage. Attention will also be given to the use of STEP-NRF and the XML and HDF5 standards for the exchange of lumped parameter thermal network models and their results. Examples of such tools are ESATAN and the various SINDAs. The results of prototyping activities in this area will be presented.

THERMAL PAPER SESSION

Chairs: J. Saiz, NASA/Johnson Space Center
Dr. E. Ungar, NASA/Johnson Space Center

A Simplified, Closed-Form Method for Screening Spacecraft Orbital Heating Variations

S. L. Rickman, NASA/Johnson Space Center

ABSTRACT:
A closed-form analytical technique has been developed to screen orbital average heating variations as a function of beta angle, altitude, surface area, and surface optical properties. Using planetary view factor equations for surfaces parallel-to and normal-to the local vertical, a cylindrical umbral shadow approximation, and a simplified albedo flux model, heating rate equations are formulated and then integrated to obtain orbital average heating. The results are compared to detailed analytical predictions using Monte Carlo integration and an assessment of error is presented.

Use of TSS as a Neutral Format For Geometry Model Conversions: an Alternative to STEP-TAS

H. Peabody, Swales Aerospace

ABSTRACT:
In today's spacecraft industry, multi-national projects are becoming more common, requiring a sharing of models across different platforms and formats. Companies and organizations in the United States have a wide range of radiative/geometry modelers from which to choose, including: TSS, TRASYS, Thermal Desktop, TMG, NEVADA, and FEMAP, to name a few. Similarly, European companies choose primarily between ESARAD and Thermica. With each company working in a preferred geometry modeler, the task of integrating each of the subcomponents into a single model and format becomes increasingly difficult.

Recently, the European Space Agency has made efforts to develop a compatible neutral format for the exchange of thermal models called STEP-TAS. Unfortunately, STEP-TAS is not yet ready for widespread use. In the meantime, thermal analysts must use existing tools or manually convert the model to the desired format. Given the detail and complexity of today's models, this can be a time consuming and demanding task.

Swales Aerospace has been involved in a number of international cooperative projects including MetOp, SECCHI, EOS-Aura, and EIS. Each of these NASA projects has required model conversion to a single consistent format for the spacecraft provider. For MetOp, Swales frequently needed to convert TSS models to ESARAD. For the SECCHI (STEREO Mission) and EOS-Aura projects, it was necessary to convert a Thermica model to TSS for internal use. The reverse was needed for the EIS project where a TSS model was converted to Thermica.

While it is generally agreed that the use of a neutral format is the best approach, opinions vary on which neutral format is best. TSS was selected as a neutral format for the necessary conversions, given Swales' familiarity with its capabilities and its prevalence in the US aerospace industry. Through the aforementioned projects, Swales has developed Visual Basic algorithms to convert ESARAD and Thermica to TSS and back. While the primary focus has been conversion to and from European modeling tools, the capabilities exist to interface to any other ASCII format.

The use of TSS as a neutral format for geometry model conversions and the subsequent development of the conversion algorithms has saved a significant amount of time and money. This paper seeks to highlight some of the capabilities of the algorithms and document some case studies in which the algorithms were used. Allowing the computer to convert the geometry models allows for a more efficient turn around time of model submission. In turn, this allows the thermal engineer to focus on more important analysis tasks, rather than spending resources converting geometry models.

Thermal/Stress Analyses of SHARP-B2 Flight Experiment Components
Thomas H. Squire, NASA/Ames Research Center
Frank S. Milos, NASA/Ames Research Center
Y.-K. Chen, NASA/Ames Research Center

ABSTRACT:
The SHARP-B2 flight experiment was designed to test the thermal and mechanical performance of Ultra-High Temperature Ceramic (UHTC) components in a realistic reentry environment. Four UHTC strakes were integrated onto an Air Force reentry vehicle and successfully flown on a ballistic reentry trajectory in September 2000. The pre- and post-test analyses of the UHTC strakes required the integration of analysis tools from various disciplines. Surface aerodynamic heating conditions were generated using a combination of CFD and engineering approximation tools. The boundary conditions were applied to various finite element models of the strake assembly, and transient coupled thermal/stress analyses were performed to predict the material response. Other analyses included predictions of part interference due to thermal expansion, and radiation heat transfer between internal components. Results of the analyses are presented as time histories of various quantities at critical locations in the model, and as 3-D contour plots of temperature and stress distributions at critical times during the flight. Comparisons are made between the predictions and flight test data. Conclusions are drawn about the accuracy of the predictions and the effectiveness of the analysis process and suggestions are made for improving the process.

Thermal Orbital Environmental Parameter Study on the Propulsive Small Expendable Deployer System (ProSEDS) Using Earth Radiation Budget Experiment (ERBE) Data

John R. Sharp, NASA/Marshall Space Flight Center

ABSTRACT:
The natural thermal environmental parameters used on the Space Station Program (SSP 30425) were generated by the Space Environmental Effects Branch at NASA's Marshall Space Flight Center (MSFC) utilizing extensive data from the Earth Radiation Budget Experiment (ERBE), a series of satellites which measured low earth orbit (LEO) albedo and outgoing long-wave radiation. Later, this temporal data was presented as a function of averaging times and orbital inclination for use by thermal engineers in NASA Technical Memorandum TM 4527. The data was not presented in a fashion readily usable by thermal engineering modeling tools and required knowledge of the thermal time constants and infra-red versus solar spectrum sensitivity of the hardware being analyzed to be used properly. Another TM was recently issued as a guideline for utilizing these environments (NASA/TM-2001-211221) with more insight into the utilization by thermal analysts. This paper gives a top-level overview of the environmental parameters presented in the TM and a study of the effects of implementing these environments on an ongoing MSFC project, the Propulsive Small Expendable Deployer System (ProSEDS), compared to conventional orbital parameters that had been historically used.

Evolving the Fluids Integrated Rack (FIR) Thermal Control System Model from an Analysis Tool to a Design and Decision Tool

Paul Gebby, Northrop Grumman

ABSTRACT:
The Fluids Integrated Rack (FIR) is a GRC developed facility to be installed in the US Lab on ISS in 2004. Its purpose is to house, sustain, and support microgravity fluid physics experiments. The first useful rack level thermal model was developed in Excel. This model routed resources, predicted heat exchanger performance, and predicted environmental temperatures in the science volume. The fidelity and capability of the model has increased with the development of a rack level model in Matlab/Simulink. This new model can account for transients, conceptual changes, and variations in active thermal control systems. These improvements in rack level modeling have allowed the FIR design team to save time and schedule on vendor developed parts, model various control schemes, and map operational characteristics during experiment cycling. Future plans for the model include the addition of temperature modeling of key components, blower performance (pressure versus flow rate and power consumption), and integration of test results and PI provided hardware.

Modeling of Multi-Layer Insulation Layups with Transmissive Outer Layers

Eugene K. Ungar, NASA/Johnson Space Center

ABSTRACT:
Multi-Layer insulation typically is made up using either CHEMGLAS 250 or Orthofabric as the outer layer. Because of the transmissive nature of both these fabrics, the second layer of the MLI participates in the radiation interchange. Although the effective emissivity in the solar and infrared ranges for layups like these can be measured using conventional equipment, these values cannot be used directly in a single surface thermal analysis. More complex analytical techniques must be used to provide an accurate result.

In the present work the physics of radiation interchange in layups of this type is explored. Measurements of effective emissivity in the solar and infrared ranges for Chemglass-250 and Orthofabric alone and with various backing materials are presented. The emissivity and transmissivity of the fabrics in the solar and IR ranges are calculated using these data. Various analytical techniques are explored and a recommendation is made for the proper technique to use in performing radiation analysis of layups of this type.

Near-Real Time Thermal Model Matching on the Shuttle

A. Hensley, I. Carron, C. Akram, U. Abbas
Commercial Space Center for Engineering/Texas A&M University

ABSTRACT:
Starnav I is a COTS startracker payload to be flown on the inaugural flight of SPACEHAB's Quick External Science Tray (QUEST). In order to provide required operational support for this payload during the STS-107 mission, the thermal team at the Commercial Space Center for Engineering (CSCE) at Texas A&M University has created a thermal model capable of answering potential questions from the JSC Operations team. Unlike the International Space Station (ISS), the shuttle vehicle can change its attitude in order to perform different maneuvers. Because of its high location in the payload bay, Starnav I is more sensitive to changes of attitudes than other payload in the payload bay. This presentation will show the different tests and modeling performed in support of this flight. We will also show our approach to a real time thermal model correction based on data gathered from the Orbiter. Starnav I will be the first experiment to collect temperature data at such elevated height in the payload bay (top of SPACEHAB module).

Fundamental Study of Heat Pipe Design for High Heat Flux Source

Ryoji Oinuma, Texas A&M University
Frederick R. Best, Texas A&M University

ABSTRACT:
As the demand for high performance small electronic devices has increased, heat removal from these devices for space use is approaching critical limits. A loop heat pipe (LHP) with coherent micron-porous evaporative wick is suggested to enhance the heat removal performance for the limited mass of space thermal management system. The advantage of LHPs to have accurate micron-order diameter pores which will give large evaporative areas compared with conventional heat pipes per unit mass. Also this design make it easy to model the pressure drop and evaporation rate in the wick compared with the evaluation of the heat pipe performance with a stochastic wick. This gives confidence in operating limit calculation as well as the potential for the ultra high capillary pressure without corresponding pressure penalty such as entrainment of the liquid due to the fast vapor flow. The fabrication of this type heat pipe could be achieved by utilizing lithographic fabrication technology for silicon etching. The purpose of this paper is to show the potential of a heat pipe with a coherent micron-porous evaporative wick from the view point of the capillary limitation, the boiling limitation, etc. The heat pipe performance is predicted with evaporation models and the geometric design of heat pipe is optimized to achieve the maximum heat removal performance per unit mass.

Wireless Temperature Sensors for Health Monitoring of Aerospace Thermal Protection Systems

F. Milos, NASA/Ames Research Center
J. Pallix, NASA/Ames Research Center

ABSTRACT (DRAFT ONLY):
Health diagnostics is an area where major improvements have been identified for potential implementation into the design of new reusable launch vehicles in order to reduce life-cycle costs, to increase safety margins, and to improve mission reliability. NASA Ames is leading the effort to advance inspection and health management technologies for thermal protection systems. This paper summarizes a joint project between NASA Ames and industry partners to develop "wireless" devices that can be embedded in the thermal protection system to monitor temperature or other quantities of interest. These devices are sensors integrated with radio-frequency identification microchips to enable non-contact communication of sensor data to an external reader that may be a hand-held scanner or a large portal through which the entire vehicle may be passed. Both passive and active (battery assisted) prototype devices have been developed. The passive device uses a thermal fuse to indicate the occurrence of excessive temperature. The active device uses a thermocouple to measure temperature history.

FLUIDS PAPER SESSION

Chair: Barbara Sakowski, NASA/Glenn Research Center

The Fractional Step Method Applied to Simulations of Natural Convective Flows

Douglas G. Westra, NASA/Marshall Space Flight Center
Dr. Juan C. Heinrich, Professor, Aerospace and Mechanical Engineering Department, University of Arizona

ABSTRACT:
The Fractional Step Method (FSM), also known as the projection method and as the splitting method has been applied commonly to high Reynolds number flow simulations, but is less common for low Reynolds number flows, such as natural convection in permeable media. The FSM offers increased speed and reduced memory requirements by allowing the non-coupled solution of the pressure and the velocity components.

The FSM is expected to offer significant benefits for predicting flows in a directionally solidified alloy, since other methods presently employed are not efficient. Previously, the most suitable finite elements based method for predicting flow in a directionally solidified binary alloy has been the penalty method. The penalty method has the disadvantage that it requires the coupled solution of the velocity components using direct matrix solvers, due to the penalty term. The FSM allows the decoupled iterative solution of the finite element equations, thereby greatly increasing the efficiency of the method. The FSM also lends itself to parallel processing, since the velocity component stiffness matrices can be built and solved independently of each other.

Numerical simulations are now commonly used to predict macrosegregation in directionally solidified castings. In particular, the finite-element simulations can predict the existence of "channels" within the processing mushy zone and subsequently "freckles" within the fully processed solid, which are known to result from macrosegregation, due to thermo-solutal convection of the melt during the solidification process. Freckles cause strong material non-uniformities in the castings which are therefore scrapped.

The phenomena of natural and thermosolutal convection in an alloy undergoing directional solidification will be explained. The momentum and continuity equations for natural convection in a fluid, a permeable medium, and in a binary alloy undergoing directional solidification will be presented. Finally, results for natural convection in a pure liquid, natural convection in a medium with a constant permeability, and for a fluid layer overlying a mushy zone solidifying directionally will be presented.

Vortex Phase Separation in Microgravity

David Bean, Department of Nuclear Engineering, Texas A&M University
Fredrick Best, Department of Nuclear Engineering, Texas A&M University

ABSTRACT:
Conservation and recycling of air and water is an important and necessary feature for long duration space missions since space systems are sensitive to volume, mass, and power. Regenerative life support systems currently being investigated require phase separators to separate the liquid from the gas produced. Typically, phase separation relies on capillary forces with a slow throughput or motor driven machines that utilize power. Vortex phase separators utilize the fluid's intrinsic momentum to produce a radial acceleration to drive the separation process. Fluid momentum forms a gas core surrounded by a liquid film during separator operation in micro-gravity. Vortex separators are passive and have no moving parts, which are attractive in terms of power. Their compact and simple design are attractive in terms of mass and volume.

Vortex formation and stability is a function of the rotational velocity of the fluid and liquid inventory. The various forces acting on the vortex, such as capillary and inertial forces, are dominant under different conditions. If the rotational velocity of the liquid is not high enough, a bubble and not a core forms and separation does not occur. If the rotational velocity is too high, we are wasting power, which defeats the purpose of using a power saving device in the first place. Texas A&M University, along with the Center for Space Power, has designed and fabricated a vortex type phase separator. Furthermore, the Texas A&M University separator has been identified by Johnson Space Center for inclusion in the "Immobilized Microbe Micro gravity Water Processing System" (IMMWPS) shuttle experiment. We used NASA's KC-135 to study the force balance to try to better understand what the operational boundary conditions of the phase separator are in order to maintain separation while saving power at the same time.

Integrating Thermal Desktop, SINDA/FLUINT and ROCETS to Perform a Coupled Conjugate Heat Transfer and Cycle Analysis for Rocket Based Combined Cycle Engines

Barbara Sakowski, NASA/Glenn Research Center
Jim Yuko, NASA/Glenn Research Center

A complete thermal and fluid systems analysis for a Rocket-Based Combined Cycle (RBCC) type vehicle would optimally link the cycle analysis of the vehicle with the thermal and fluid systems analysis of the vehicle. Furthermore it would be advantageous if the cycle analysis could be dynamically linked to the thermal and fluids systems analysis. This would avoid the repetitive and tedious process of manually inputting the results of the cycle analysis as boundary conditions in the thermal and fluids systems analysis, and subsequently inputting those results as boundary conditions in the cycle analysis until a converged solution is achieved. The goal of this paper is to illustrate such an interface between the ROCket Engine Transient Simulator (ROCETS), a cycle

analysis code, and a thermal and fluid systems analysis code, SINDA/FLUINT and Thermal Desktop.

ORSAT Parametric Study

Christopher B. Madden
NASA/Johnson Space Center

ABSTRACT:
A parametric study of the survivability of reentry space debris is presented. Since space debris can be of various size and shapes, a thorough parametric study can help to identify high risk items for reentry survival. In this analysis, a series of spheres and cylinders were analyzed using the Object Reentry Survivability Analysis Tool (ORSAT) to determine the degree of demise during reentry flight. ORSAT is a multi-discipline tool which can analyze spheres, cylinders, flat plates, and other objects with multiple materials. All of the pertinent object parameters such as diameter, wall thickness, density, initial temperature, and initial state vector information such as altitude, flight path angle, and velocity are input to appropriately define the solution space. The solutions are presented in graphical and table form. It is shown in this analysis that sphere and cylinder survivability is most dependent on the object size, specifically ballistic coefficient. It is seen that both a large and small sphere can survive, while a medium size sphere tends to demise in the atmosphere.

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PROPULSION PAPER SESSION

Chair: Eric Hurlbert, NASA/Johnson Space Center

Numerical Modeling of Cavitating Venturi – A Flow Control Element of Propulsion System

Alok Majumdar, NASA/Marshall Space Flight Center (Thermodynamics & Heat Transfer Group)

ABSTRACT:
In a propulsion system, the propellant flow and mixture ratio could be controlled either by variable area flow control valves or by passive flow control elements such as cavitating venturies. Cavitating venturies maintain constant propellant flowrate for fixed inlet conditions (pressure and temperature) and wide range of outlet pressures, thereby maintain constant, engine thrust and mixture ratio. The flowrate through the venturi reaches a constant value and becomes independent of outlet pressure when the pressure at throat becomes equal to vapor pressure. In order to develop a numerical model of propulsion system, it is necessary to model cavitating venturies in propellant feed systems. This paper presents a finite volume model of flow network of a cavitating venturi. The venturi was discretized into a number of control volumes and mass, momentum and energy conservation equations in each control volume are simultaneously solved to calculate one-dimensional pressure, density, and flowrate and temperature distribution. The numerical model predicts cavitations at the throat when outlet pressure was gradually reduced. Once cavitation starts, with further reduction of downstream pressure, no change in flowrate is found. The numerical predictions have been compared with test data and empirical equation based on Bernoulli's equation.

Auxiliary Propulsion System Analysis Tool (APSAT) for Sizing Vehicles

Kris Romig, NASA/Johnson Space Center (Propulsion and Fluid Systems Branch)

ABSTRACT:
The Auxiliary Propulsion System Analysis Tool (APSAT) was created for use in an integrated design environment to rapidly conduct conceptual vehicle sizing studies. This program primarily sizes orbital maneuvering and reaction control systems but can also be used to size main propulsion for small spacecraft for transfer burns along with attitude control. The vehicle applications include lander vehicles, crew transfer vehicles, RLV OMS/RCS, etc. This model provides the capability to do hundreds of possible combinations of propellant type, tank materials, mixture ratios, etc. using an automated process. The automation of this process helps to decrease analysis time and increase accuracy and fidelity of the various design studies performed.

Non-Toxic Auxiliary Propulsion System Modeling of Liquid Oxygen Tank and Accumulator for Ground Tests

Kevin J. Miller
Eric Hurlbert
NASA/Johnson Space Center (Propulsion and Fluid Systems Branch)

ABSTRACT:
A thermal and fluid analysis of a liquid oxygen tank and feedsystem is being performed to support non-toxic propulsion system ground test bed activities. The test bed is to demonstrate the technologies required for implementing a liquid oxygen and ethanol auxiliary propulsion system. The cryogenic tank, feedlines, and accumulator were modeled using the SINDA/FLUINT thermal/fluid network analyzer. The objectives of the analysis are to determine loading and chilldown timelines in order to meet a 1-hour maximum time allotted to complete loading 4600 lbm of LO2 into the tank, feedlines and accumulator. The results determined the orifice sizes required to vent the boil-off and the effect of orientation on the bellows accumulator thermal response. The model was used to establish the feasibility of meeting the 1-hour loading time requirement. The current model might be further developed to include all phases of test bed system operation including multiple thruster firings and long quiescent periods.

Cryogenic RCS Feedsystem Test and Analysis

Kris Romig
Kevin J. Miller
NASA/Johnson Space Center (Propulsion and Fluid Systems Branch)

ABSTRACT:
One of the main objectives of the CRFT program is to demonstrate the feasibility of maintaining liquid oxygen conditions at the inlet to an injector valve for an equivalent orbiter RCS engine. For safety reasons the test article uses liquid nitrogen instead of liquid oxygen. This feedsystem is equivalent to a single RCS shuttle manifold with the addition of a 110ft transfer line simulating the transfer line to the forward pod of the orbiter or an orbiter like vehicle.

Making use of SINDA/FLUINT as an analysis tool a thermal and fluid model of the CRFT test article was created. This model allows for easy examination of the effects of changes to the test article as well as projecting LOx performance from LN_2 test data. The model also allows for full transient simulation of the feedsystem with changes to key variables such as valve control logic (temperature set points), supply tank pressure and temperature, working fluid, etc. This thermal fluid model has aided the advancement of the CRFT program in that it has helped to optimize the temperature control ranges for the best performance from the system, as well as demonstrating the effects of additional layers of MLI, and helping to flush out some of the inherent heat leaks into the test system.

In-Situ Resource Utilization Thermal, Fluids, and Process Modeling

Tom Simon, NASA/Johnson Space Center (Propulsion and Fluid Systems Branch)

ABSTRACT:
Modeling of In-Situ Resource Utilization technologies and systems have been performed to support trade studies and ground testing. The models are used to determine promising methods and technologies of producing consumables for various missions including both robotic and manned missions to the moon and Mars. Testing of these technologies and overall systems rely on the models to help size components and operating procedures for specific production goals. This presentation will focus on the modeling done in support of an ISRU system that is sized for a robotic Mars sample return mission, producing 32 grams/hour of methane and 62 grams/hour of oxygen. The main technologies of the system to be covered are the water electrolysis unit and Sabatier reactor, including testing to date.